

SEARCH FOR EXTRA GAUGE BOSONS IN LITTLE HIGGS MODELS AT A LINEAR COLLIDER

GI-CHOL CHO

*Department of Physics, Ochanomizu University,
Tokyo, 112-8610, Japan*

AYA OMOTE

*Graduate School of Humanities and Sciences,
Ochanomizu University, Tokyo, 112-8610, Japan*

A generic feature of little Higgs models is presence of extra neutral gauge bosons. In the littlest Higgs model, the neutral extra gauge boson A_H is lightest among the extra particles and could be as light as a few hundred GeV, which may be produced directly at an e^+e^- linear collider. We study production and decay of A_H at the linear collider and compare them with those of Z' bosons in supersymmetric E_6 models.

1 Introduction

The idea of little Higgs^{1,2,3} has been proposed as an alternative of supersymmetry to solve the gauge hierarchy problem. In this class of models, the electroweak Higgs boson appears as a pseudo-goldstone boson of a certain global symmetry breaking at a scale $\Lambda \sim 10$ TeV so that the Higgs boson mass can be as light as $O(100)$ GeV. The light Higgs boson mass is protected from the 1-loop quadratic divergence by gauging a part of global symmetry, and introducing a few extra heavy particles whose typical mass scale is of order $f \equiv \Lambda/4\pi$, where f is a decay constant of the pseudo-goldstone boson. A generic feature of the little Higgs models is a larger gauge symmetry than the Standard Model (SM), which is broken near the electroweak scale, so that there are some extra gauge bosons at the TeV scale.

In this talk, we would like to study production and decay of the extra gauge bosons at a future e^+e^- linear collider. Especially we focus on the Littlest Higgs Model (LHM) which is the simplest and earliest one in this class of models⁴. The LHM has $[\mathrm{SU}(2) \times \mathrm{U}(1)]^2$ symmetry at ultra-violet regime, and which is broken to that of the SM, $\mathrm{SU}(2)_L \times \mathrm{U}(1)_Y$, at the scale Λ . Then, there are four massive extra gauge bosons and they are mixed with the SM gauge bosons after the electroweak symmetry breaking. As a result, the set of extra gauge bosons at the weak scale consists of electrically neutral states (A_H, Z_H) and charged states (W_H^\pm). Among them, the A_H boson is lightest so that it is expected to be discovered at future collider experiments rather early. The A_H boson in hadron collider experiments has been studied in refs.^{5,6}.

Since such an experimental signature of the A_H boson is quite similar to a Z' boson, it is very important to identify the models if an extra neutral gauge boson is discovered in hadron collider experiments. Although the LHC experiment could discover the Z' boson up to 3 TeV⁷, it is hard to test the Z' models. On the other hand, an e^+e^- linear collider can play a complementary role for such purpose⁸. In this talk, we compare the experimental signatures of A_H and those of Z' boson in supersymmetric E_6 models⁹, and examine a possibility to distinguish these models in the linear collider experiments. In our study, we assume that Tevatron or LHC discovers a certain Z' boson whose mass is smaller than \sqrt{s} of the linear collider. Then we can study the Z' boson at the linear collider by tuning the e^+e^- beam energy at the peak of Z' resonance. We also assume that the mixing with the SM Z boson is negligibly small because such a mixing is severely constrained from the experimental data of the electroweak precision measurements at the Z -pole¹⁰.

The interaction of A_H to a fermion f in the SM is described by the following Lagrangian⁵:

$$\mathcal{L} = -\frac{g_Y}{2 \sin \theta' \cos \theta'} Q_{f_\alpha}^{A_H} \overline{f_\alpha} \gamma^\mu f_\alpha A_{H\mu}, \quad (1)$$

where $\alpha (= L, R)$ denotes the chirality of fermion f , and θ' is the mixing angle of two U(1) gauge bosons. The charge $Q_{f_\alpha}^{A_H}$ for the fermion f_α is summarized in ref.¹¹. The interactions and couplings of Z' to the fermion pairs in the SUSY E_6 models – χ, ψ, η and ν models – can also be found in ref.¹¹.

We show the peak cross section of $e^+e^- \rightarrow \mu^+\mu^-$ in the LHM and SUSY E_6 models as a function of the $A_H(Z')$ mass in Fig. 1(a), and of the mixing angle $\tan \theta'$ in Fig. 1(b). In Fig. 1(a), the LHM prediction is shown for $\tan \theta' = 0.5$. On the other hand, Fig. 1(b) is obtained for $m_{A_H}(m_{Z'}) = 750$ GeV. We can see in Fig. 1(a) that the peak cross section in the LHM is roughly a few hundred pb, which is a few times larger than those in SUSY E_6 models, so the cross section measurement seems to be useful to test the models at the linear collider with 100fb^{-1} integrated luminosity. However, we can see in Fig. 1(b) that the peak cross section in the LHM rapidly decreases around $\tan \theta' = 1.2$. This is because that both the left- and right-handed electron couplings to A_H are proportional to $-\frac{2}{5} + \cos \theta'^2$, and they diminish for $\tan \theta' \sim 1.2$. Therefore, we should find another observable to test the models.

The forward-backward (FB) asymmetry of the $e^+e^- \rightarrow f\bar{f}$ process does not have the θ' dependence. The FB asymmetry at the pole of $A_H(Z')$ can be expressed as

$$A_{\text{FB}}^f = \frac{3}{4} A^e A^f, \quad (2)$$

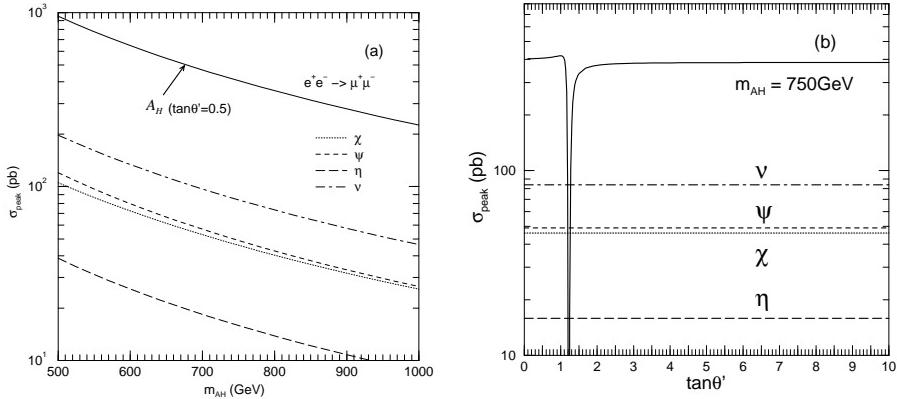


Figure 1: The peak cross section of $e^+e^- \rightarrow \mu^+\mu^-$ at the Z' pole in the LHM (solide line) and SUSY E_6 models as functions of A_H (or Z') mass (a), and of the mixing angle θ' (b).

and A^f can be expressed in terms of the parameter r_f which is defined as a ratio of the left- and right-handed couplings¹¹:

$$A^f = \frac{1 - r_f^2}{1 + r_f^2}. \quad (3)$$

It is easy to see that the parameter r_f ($f = e, u, d$) in the LHM is independent of θ' ;

$$(r_e, r_u, r_d) = (2, 4, -2). \quad (4)$$

The FB asymmetry, therefore, is a good observable to compare the LHM and the SUSY E_6 models. The FB asymmetry for the muon, c -quark and b -quark in the LHM and the SUSY E_6 models is summarized in Table 1. It is remarkable that the asymmetries in the ψ model are zero because that the extra U(1) charge assignments on the SM fermions are parity invariant. Beside on the ψ -model, the difference of predictions between the LHM and the SUSY E_6 models are very clear in the b - and c -quark asymmetries. In the b -quark FB asymmetry, the LHM predicts a positive value while the SUSY E_6 model are negative one. Especially, it is noticeable that there is no c -quark asymmetry in the SUSY E_6 models though the LHM gives a 40% asymmetry. The reason why the FB asymmetry of c -quark vanishes in SUSY E_6 models is as follows. As shown in eq. (2), the FB asymmetry is given by the difference of the couplings between the left- and right-handed fermions to the Z' boson. In SUSY E_6 models,

	A_H	χ	ψ	η	ν
A_{FB}^{μ}	0.27	0.48	0	0.27	0.27
A_{FB}^b	0.27	-0.48	0	-0.27	-0.27
A_{FB}^c	0.40	0	0	0	0

Table 1: Forward-backward asymmetry A_{FB} for muon, b and c quarks in LHM and SUSY E_6 models.

both left- and right-handed c -quarks are embedded in the same multiplet, **10** representation in SU(5), so that they have a common coupling which leads to no asymmetry. Table 1 tells us that the measurements of b - and c -quark asymmetries in a few % accuracy is enough to test if a Z' boson is A_H in the LHM or one of the SUSY E_6 models. We, therefore, conclude that the measurements of FB-asymmetries for heavy quarks are very useful to test if the Z' boson is A_H in the LHM or one of the SUSY E_6 models.

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